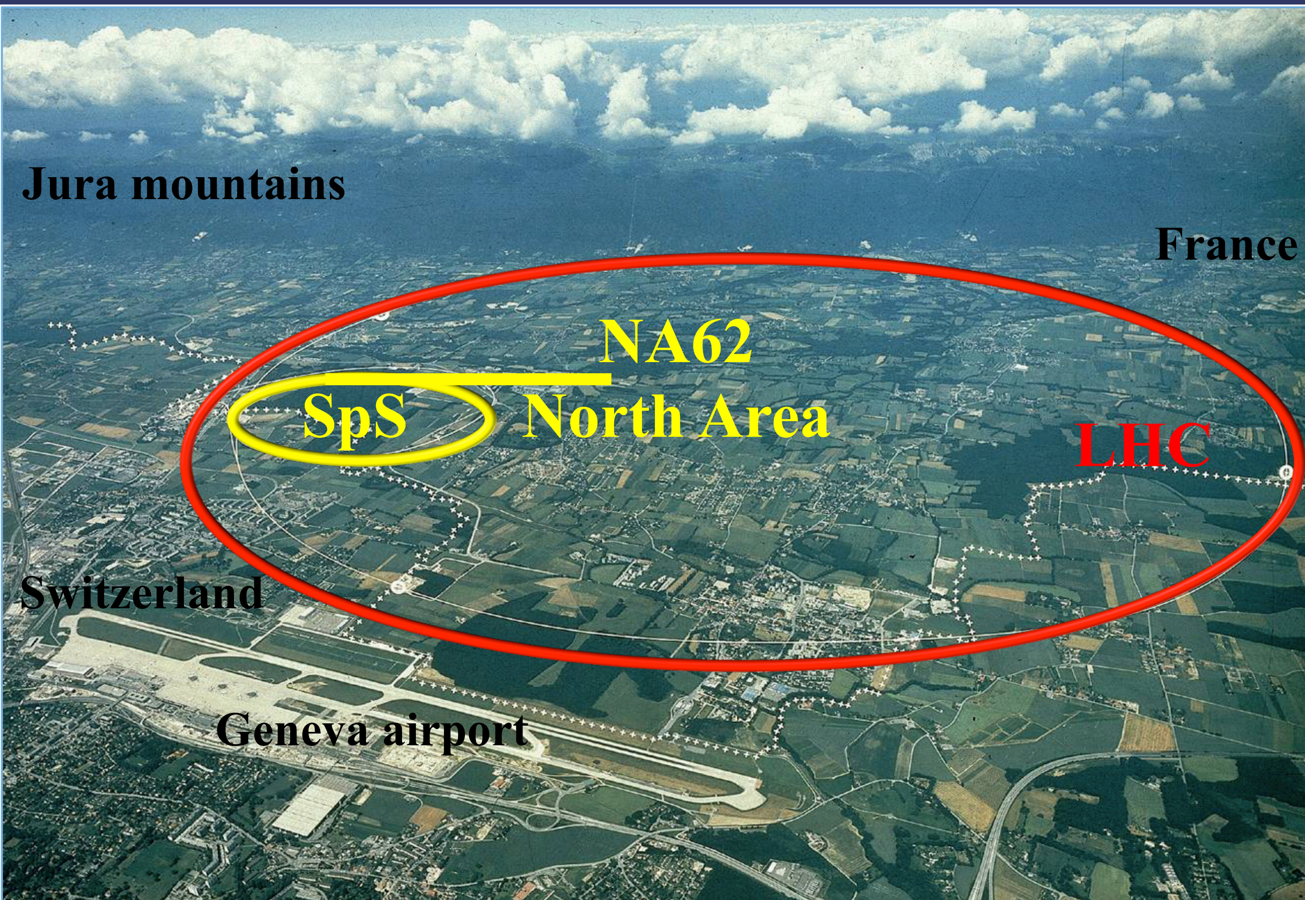
Status of NA62 experiment

Mauro Raggi,
45th meeting of the LNF scientific committee
Frascati, Nov 20th 2012

The NA62 collaboration @ CERN SpS



Goal: BR($K^+ \to \pi^+\nu\nu$) to 10%

100 signal events S/B ~ 10

10^{13} K^+ decays with:

- Acceptance ~10%
- Background rejection ~10^{12}
- Background known to ~10%

Time schedule

07-08: measurement of: $R_K = Ke2/K\mu 2$ with NA48

07-13: design, construction, installation

Nov. 2012: Technical run

from 2014: Measurement of ~100 $K^+ \to \pi^+\nu\nu$ decays

NA62 collaboration:

Birmingham, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Naples, Perugia, Pisa, RomeI, RomeII, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin

Searching for NP a different approach

Intensity frontier
Indirect investigation on new physics

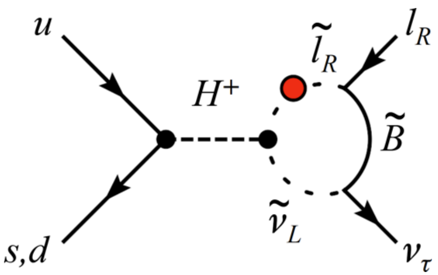
Search new degrees of freedom as alteration of SM rates. Explore symmetry properties of new d.o.f
$\Lambda \sim$ 1-1000 TeV

A rare decay
is useful as a New Physics probe if:

1) Process is (strongly) suppressed in the SM
2) Parameter to be measured precisely known in SM
3) There are specific predictions for NP contributions

Example I LFV: $R_K = K_{e2}/K_{\mu2}$

1) Ke2 process is helicity suppressed
2) R_K known theoretically to $1/10^4$
3) Deviation predicted by LFV 2HD models (~1%)



Masiero, Paradisi, Petronzio, Phys.Rev. D74 (2006) 011701

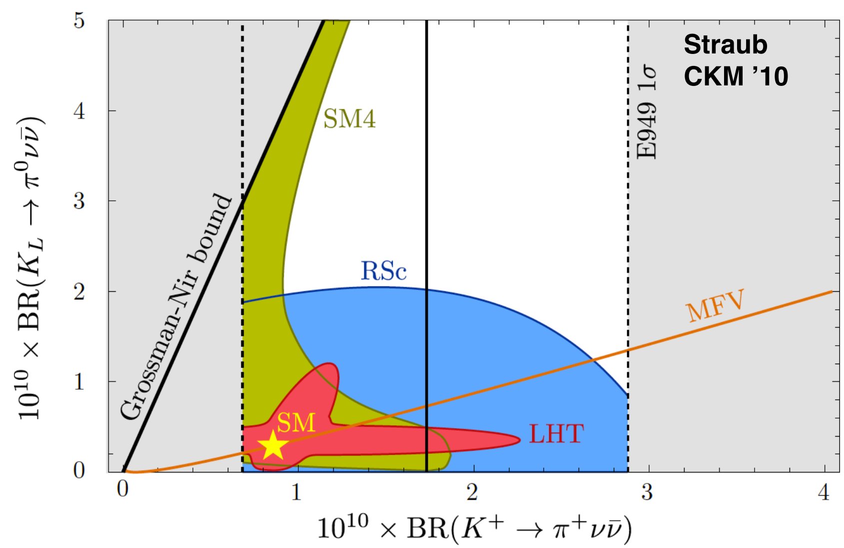
$$R_K^{LFV} \approx R_K^{SM}\left[1+\frac{m_K^4}{m_H^4}\frac{m_\tau^2}{m_e^2}|\Delta_R^{31}|^2\tan^6\beta\right]$$

O(1%) on R_K for Δ_{13}~$5 \cdot 10^{-4}$ $\tan\beta$~40 M_{H+}~500 GeV

NA62 R_K=(2.488 ± 0.007$_{stat}$ ± 0.007$_{syst}$)×10^{-5} Δ(BR)/BR=0.4%
PLB698 2011 105-114

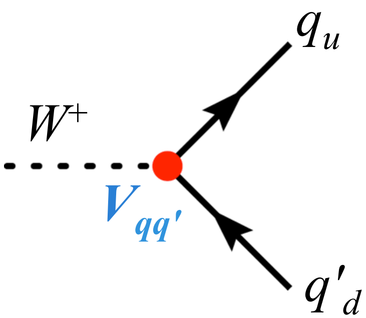
Example II FCNC: $K^+ \to \pi^+\nu\nu$

1) πνν process is GIM suppressed
2) BR(πνν) known theoretically ~10%
3) Many prediction by different NP models



The Cabbibo Kobayshi Maskawa matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathscr{O}(\lambda^4)$$



V is unitary: $\mathbf{V}^\dagger\mathbf{V} = \mathbf{1}$

$$\sum_i V_{ij} V^*_{ik} = \sum_i V_{ji} V^*_{ki} = \delta_{jk}$$

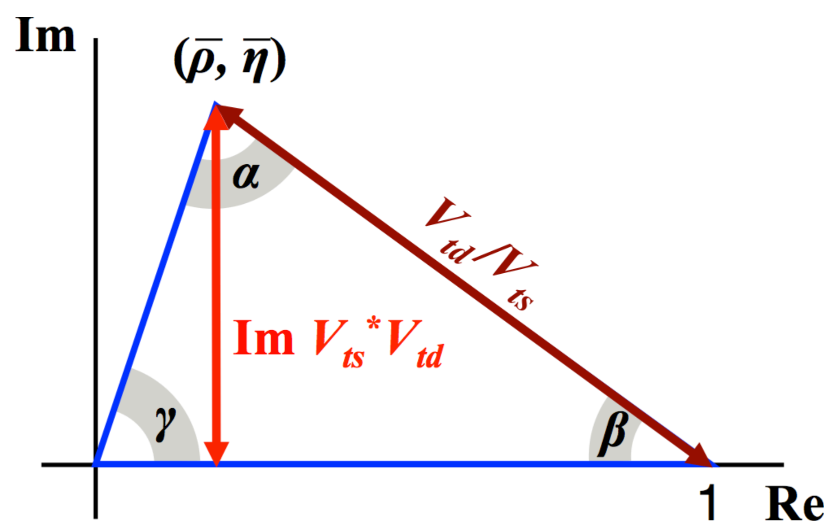
K unitarity triangle

$$V_{ud}V^*_{us} + V_{cd}V^*_{cs} + V_{td}V^*_{ts} = 0$$

B unitarity triangle

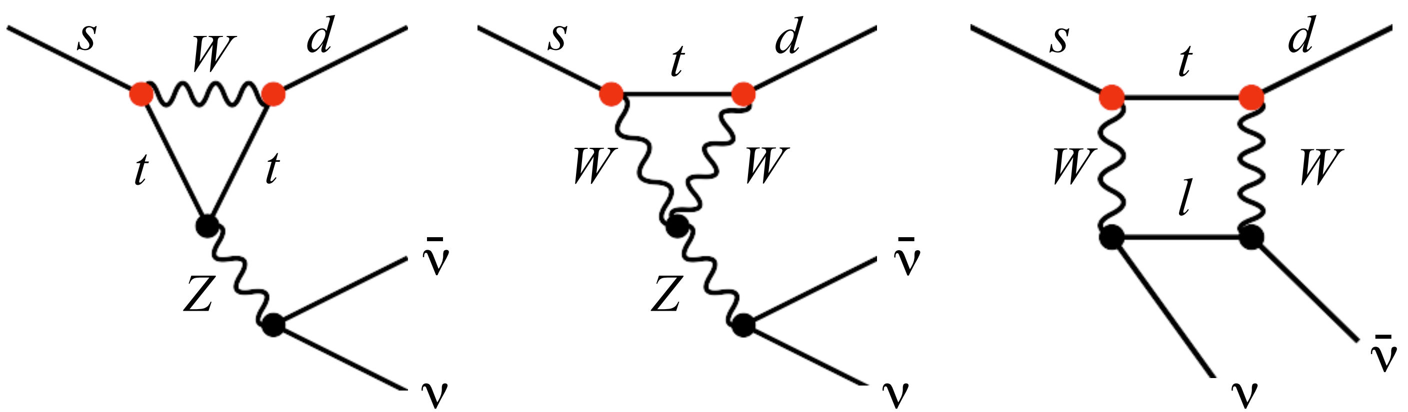
$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

Observable	Measurement
$K^+ \to \pi^+ \nu\bar{\nu}$	$\lvert V^*_{ts} V_{td} \rvert$
$K_L \to \pi^0 \nu\bar{\nu}$	$\mathrm{Im}\, V^*_{ts} V_{td} \propto \eta$
$B_d \to J/\psi K_s$	$\sin 2\beta$
$\frac{\Delta M_{B_d}}{\Delta M_{B_s}} = \frac{B_d - \bar{B}_d}{B_s - \bar{B}_s}$	$\frac{V_{td}}{V_{ts}}$



$K\to\pi\nu\nu$ in the Standard Model

Z-penguins Box diagram



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$
$$x_q \equiv m_q^2 / m_W^2$$

Loop functions favor top contribution

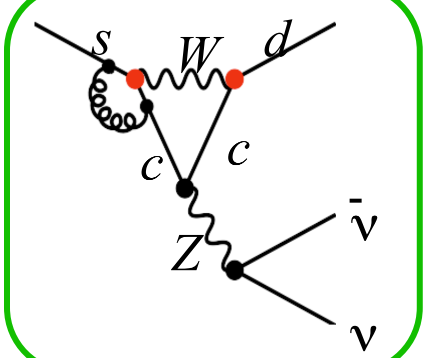
$$\mathrm{BR}(K^+\to\pi^+\nu\bar\nu) = \kappa_+ \left[\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X(x_t)\right)^2 + \left(\frac{\mathrm{Re}\lambda_t}{\lambda^5}X(x_t) + \frac{\mathrm{Re}\lambda_c}{\lambda}P_c(X)\right)^2\right]$$

$$\mathrm{BR}(K_L\to\pi^0\nu\bar\nu) = \kappa_L \left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X(x_t)\right)^2 \leftarrow \not{CP}$$

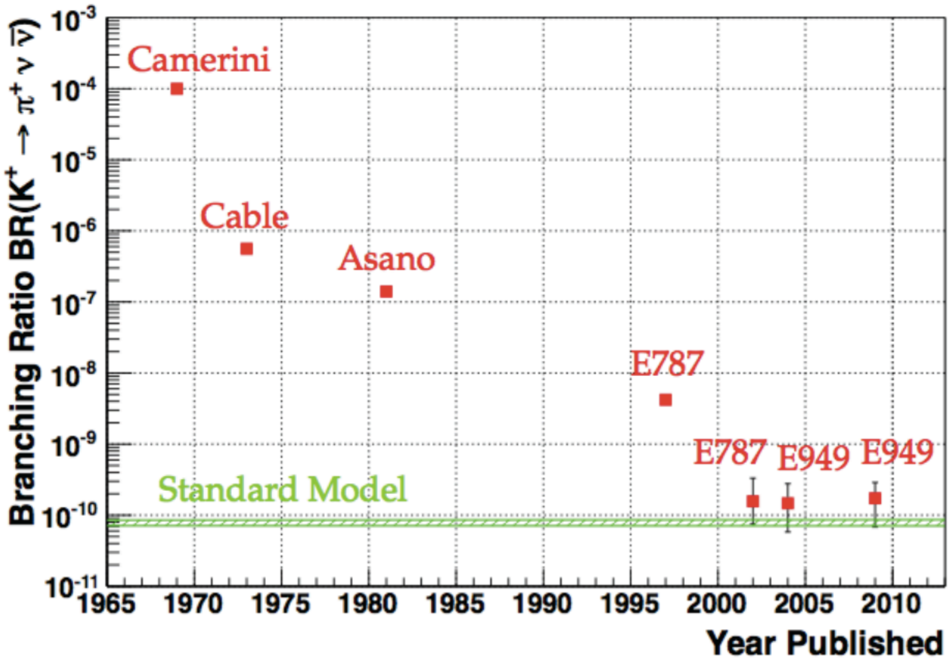
QCD corrections for charm diagrams contribute to uncertainty

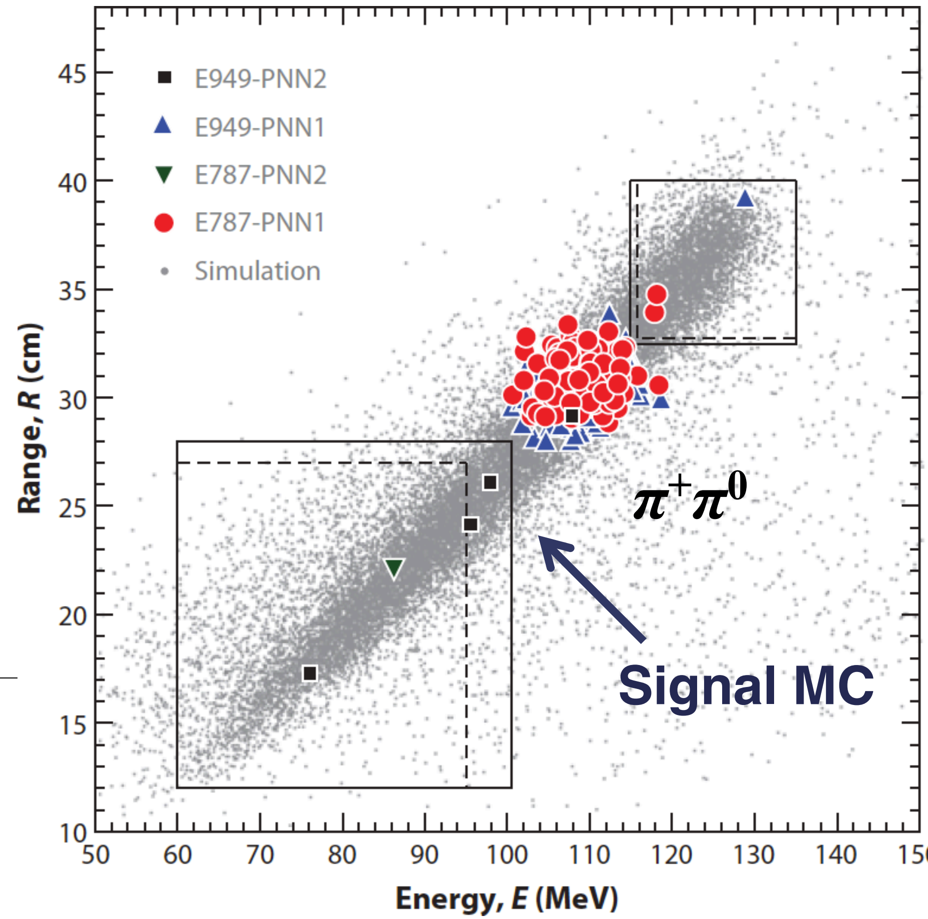
$$\kappa_+ = r_{K^+}\frac{3\alpha^2\,\mathrm{BR}(K^+\to\pi^0 e^+\nu)}{2\pi^2\sin^4\theta_W}\lambda^8$$

Hadronic matrix element obtained from BR(K_{e3}) via isospin rotation



Present status





Measurement from BNL 787/949

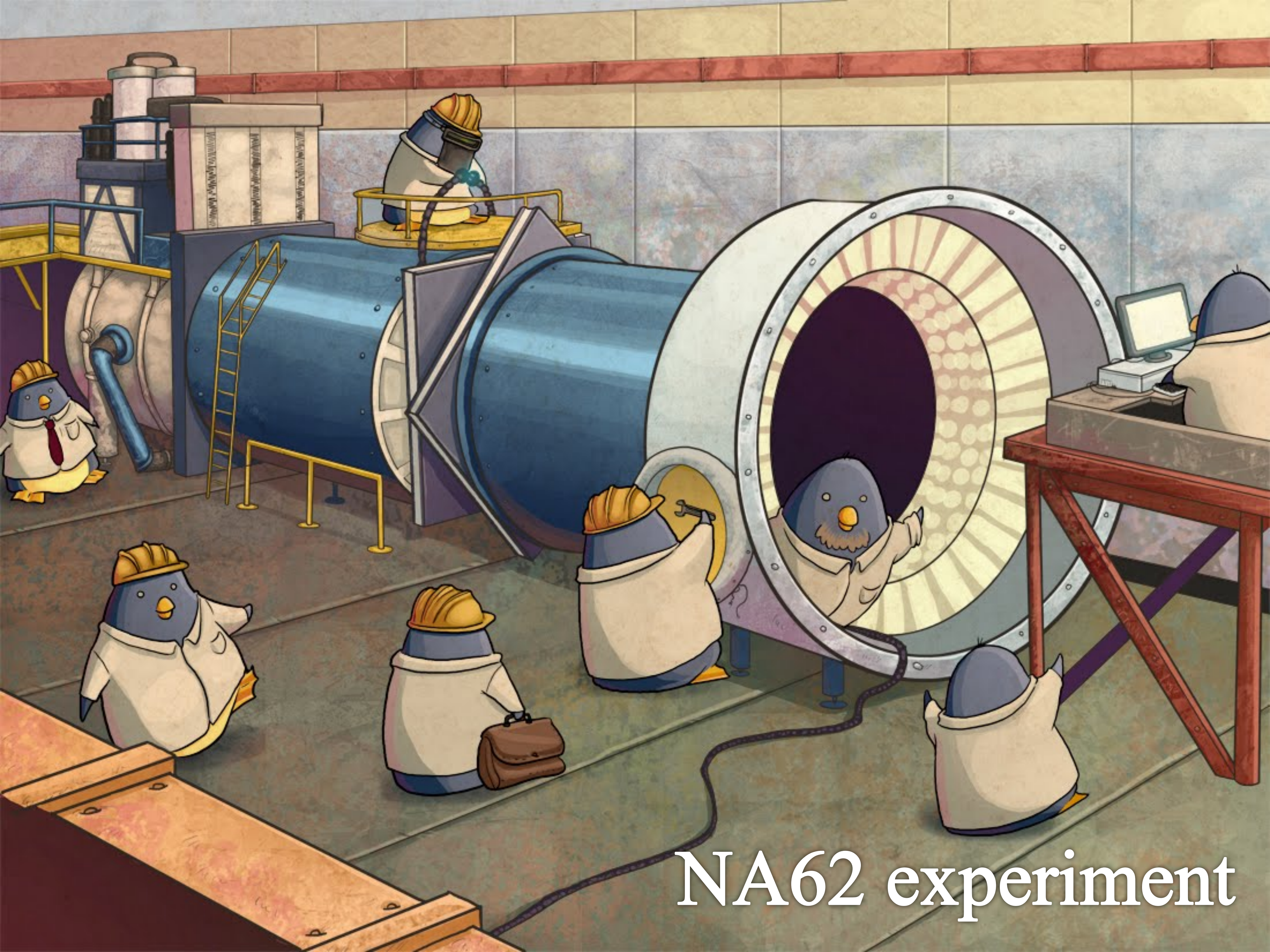
7 candidate $K^+ \to \pi^+ \nu\nu$ events

BR = $(1.73^{+1.15}_{-1.05}) \times 10^{-10}$

2× BR_{SM} but entirely consistent

J. Brod, M. Gorbahn, and E. Stamou Phys. Rev. D 83, 034030 (2011)

$$BR_{Th}(K^+ \to \pi^+ \nu \bar{\nu}) = (7.81^{+0.80}_{-0.71} \pm 0.29_{theo}) \cdot 10^{-11}$$


NA62 experiment

The measurement technique

An experimental nightmare

Very small branching ratio
- *~ 7x10^{-11}*

Weak experimental signature
- *Only a pion in the final state*
- Cannot reconstruct K mass

Huge Backgrounds
- *61% $K^+ \longrightarrow \mu^+ \nu$ decay*
- *21% $K^+ \longrightarrow \pi^+ \pi^0(\gamma)$ decay*
- *5% $K^+ \longrightarrow \pi^+ \pi^+ \pi^-$ decay*

Need rejection factors for BG up to 10^{12} to get S/BG>10

Kinematical Rejection
- *K^+* 4-mom (GigaTracker)
- π^+ 4-mom (Straw+MNP33)

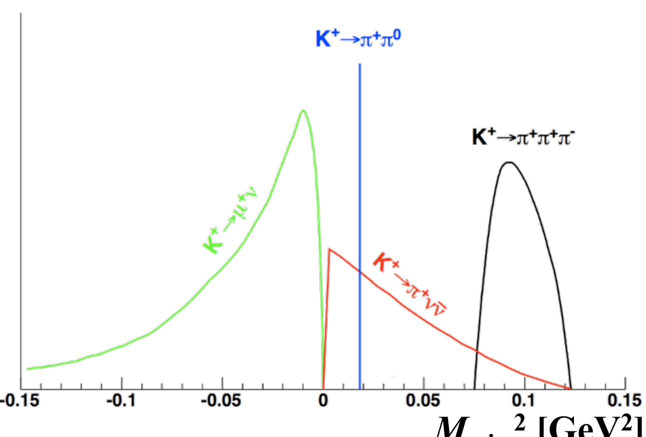
BG rejection needed ~ 10^4

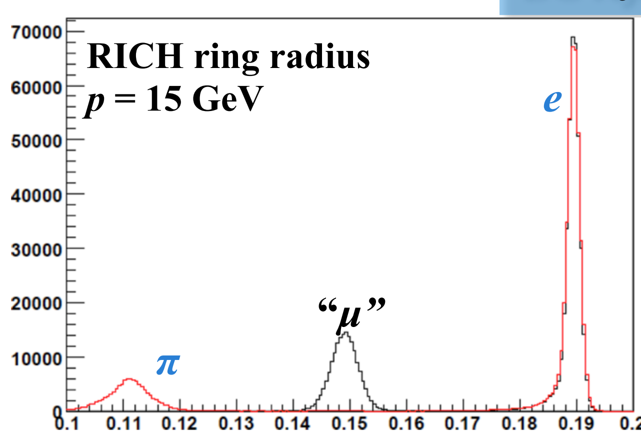
Particle ID
- Positively identify π^+ (RICH)
- Reject μ, e (RICH+MUV)
- Required up to 35 GeV

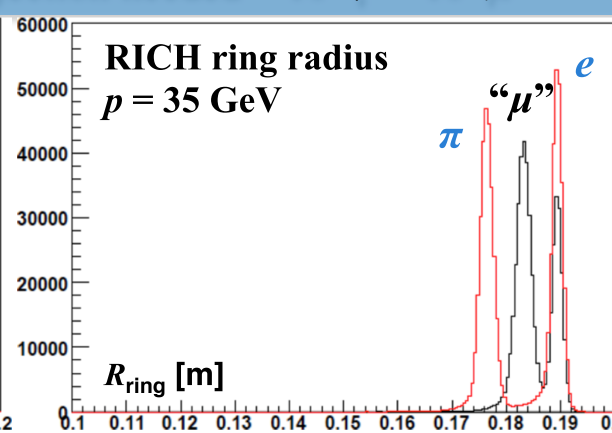
BG rejection needed ~ 10^3

Vetoes extra particles
- *Veto photons from π^0 decays*
- Veto m from beam halo and K decays
- Need to cover huge range of energies
- Need to cover all angles <50 mrad

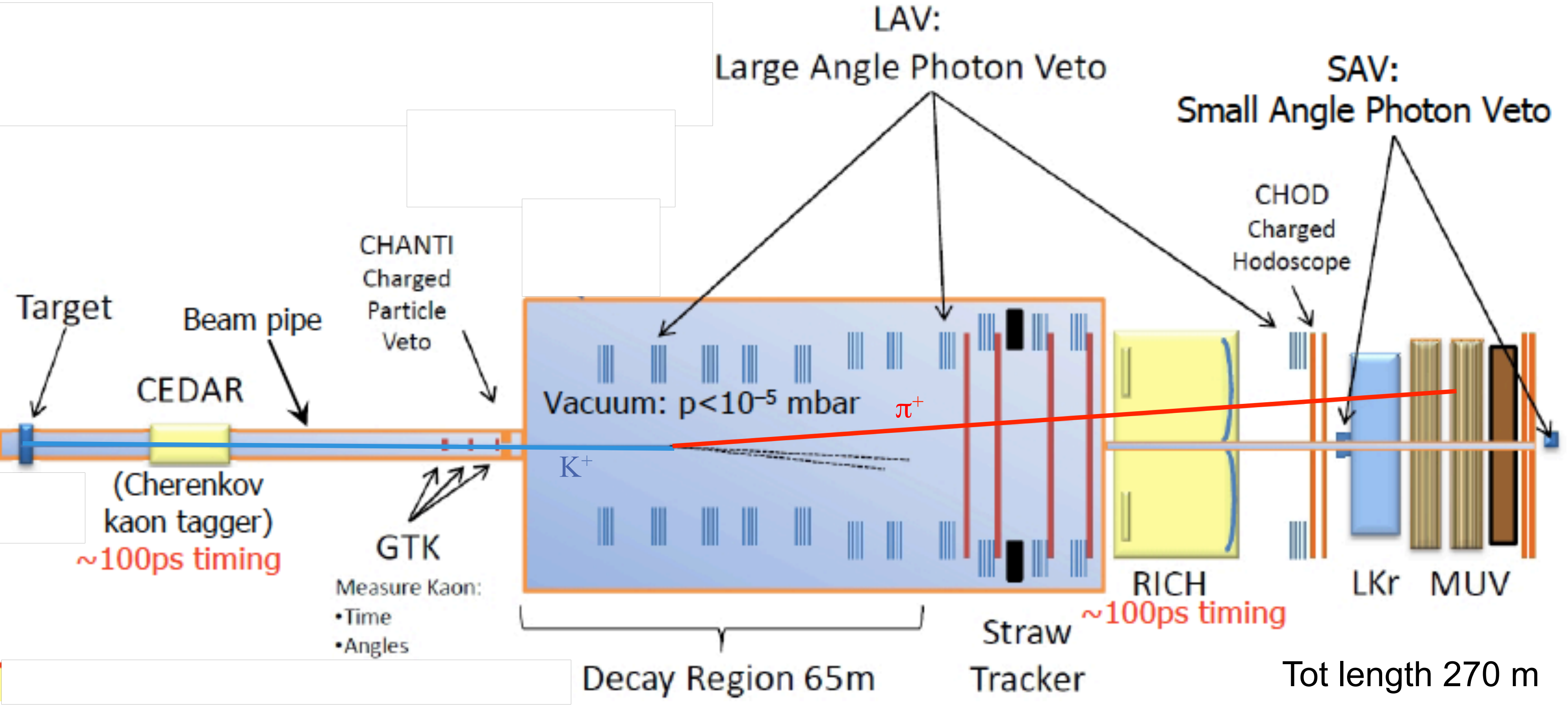
BG rejection needed ~ 10^4 γ ~ 10^5 μ







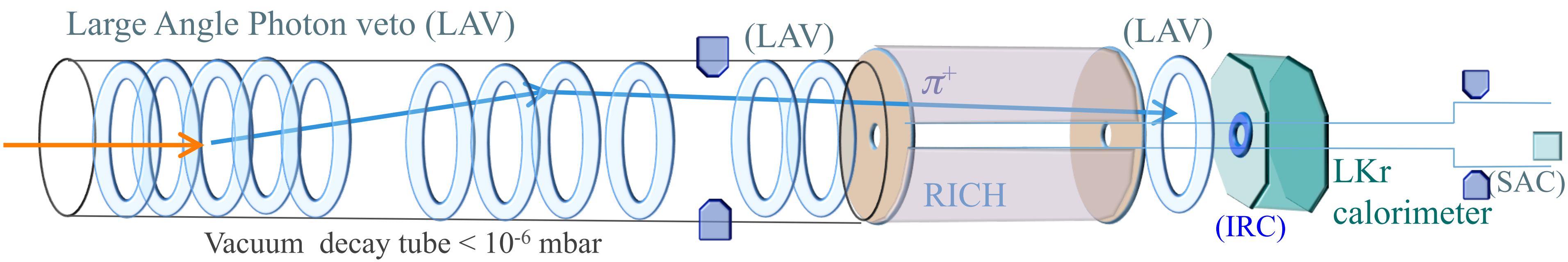
The NA62 detector

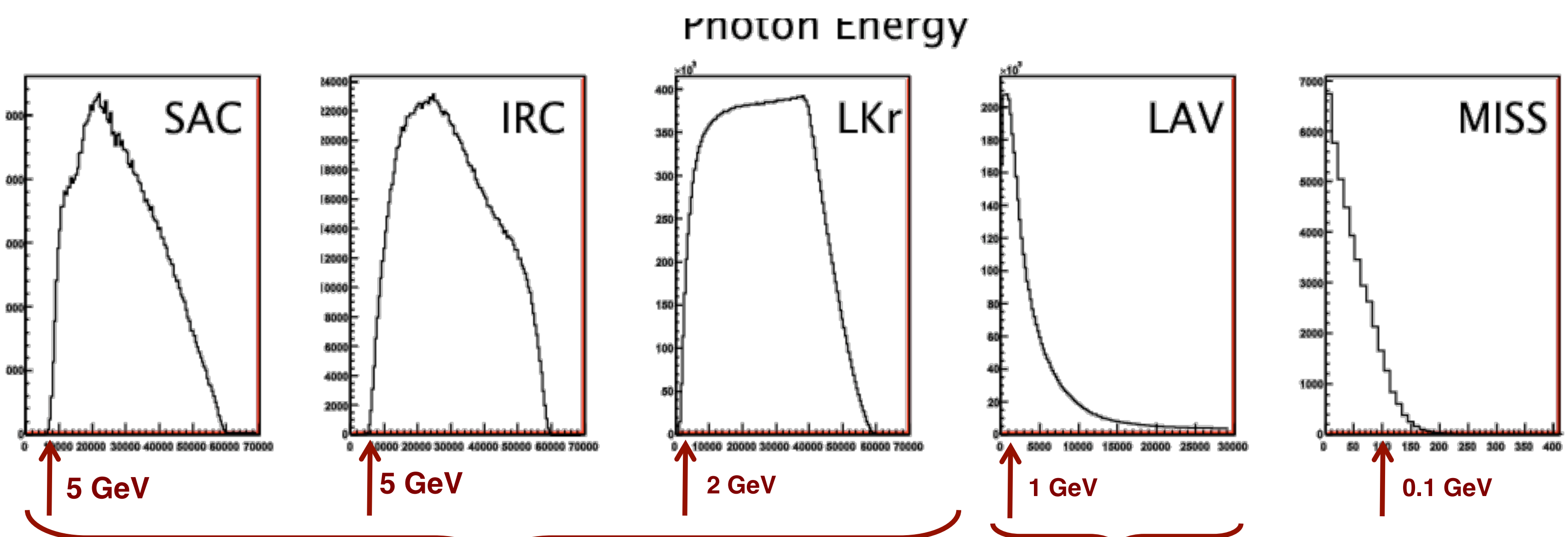


Primary protons:	3×10^{12} protons/pulse from SpS with momentum of 400 GeV
Beam:	750MHz unseparated beam: 525 MHz π^+, 170 MHz p, 45 MHz K^+
Total # kaons:	10% of K^+ decay in FV $\Rightarrow$ 4.5×10^{12} K^+ decays/yr
K^+ momentum:	(75±1) GeV
Measures:	Tag K, K and π momentum and time, π tag, veto all extra particle

The photon veto system

4 different detectors: LAV, LKr calorimeter, Intermediate ring calorimeter (IRC) and small angle calorimeter (SAC)





$\approx 10^{-5}$ γ detection inefficiency
θ in 0-8.5 mrad acceptance

$\approx 10^{-4}$ inefficiency $E_\gamma > 200$ MeV
θ in 8.5-50 mrad acceptance

LNF NA62 group

- A. Antonelli, F. Gonnella, V. Kozhuharov, G. Mannocchi, M. Martini, M. Moulson, M. Raggi, T. Spadaro
- LNF SPAS: C. Capoccia, A. Cecchetti, E. Capitolo
- Group technicians: R. Lenci, V. Russo, M. Santoni, S. Valeri, T. Vassilieva
- LNF SELF: G. Corradi, C. Paglia, D. Tagnani
- LNF vacuum service: P. Chimenti, V. Lollo
- LNF mechanics workshop: G. Bisogni
- LNF metrology: M. Paris

LNF responsibilities on LAV detector

The LNF group responsibilities in the LAV detector

- Coordination of the photon Veto System
- Design of the LAV vessel & construction equipment
- Test and calibration of the PbGl blocks
- Assembly of the LAV stations
- Vacuum, HV and electronics tests
- LAV installation on ECN3 cavern

The LNF group responsibilities in the LAV readout

- Design and testing of new HV dividers for the R2238 PMTs
- Project and development of FEE prototypes
- Production, validation and testing of the final FEE board
- Installation and commissioning of the whole LAV readout in ECN3
- Firmware for the L0 LAV trigger primitive generation

The LNF group responsibilities in software and MC

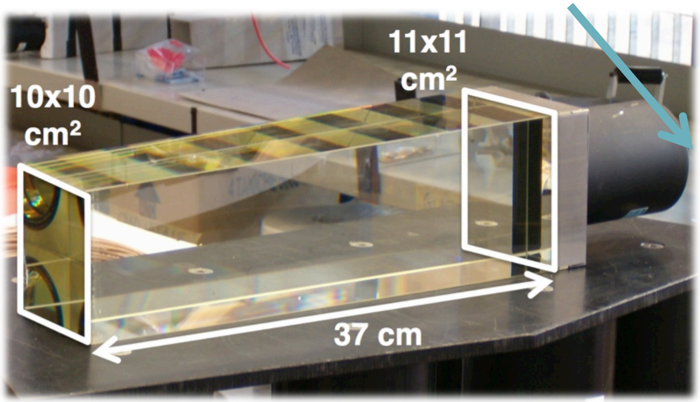
- Leading role in the LAV MC reconstruction
- Leading role in the development of new analysis tools

The LAV detector (synergy w NA,Rm1,PI)

LAV numbers

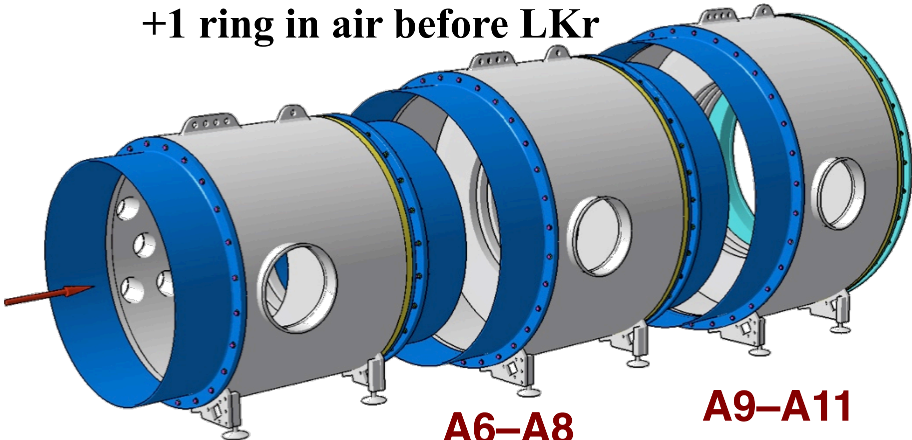
- 12 stations
- 4-5 rings/layer
- 32-64 blocks/layer
- ~ 2500 blocks total
- Operation in vacuum
- All particles from axis cross min 3 blocks ($20X_0$)

R2238 76-mm PMTμ-metal case



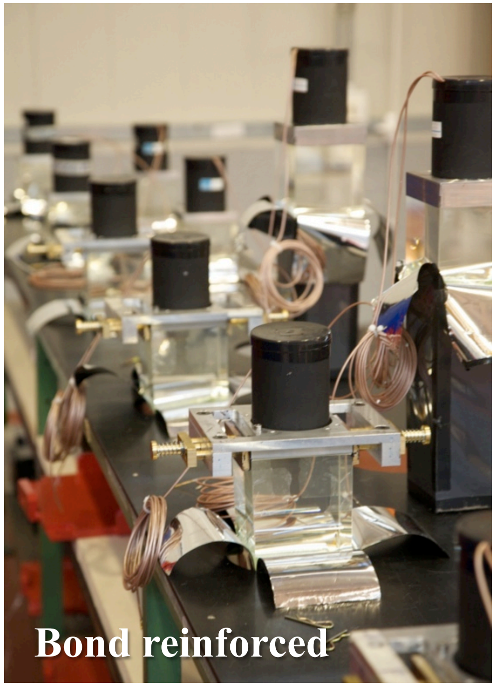
Lead-glass blocks from OPAL EM barrel
Schott SF57 lead glass

11 rings installed in vacuum tank
+1 ring in air before LKr

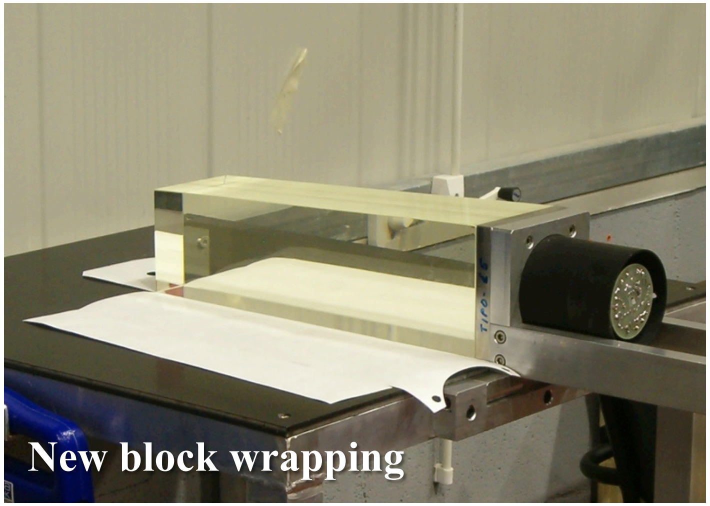


LAV construction @ LNF


Water damage


Bond reinforced

“Banana” assembly


New block wrapping


Banana installation

Completed 9 LAV now at CERN!

LAV in the ECN3 cavern

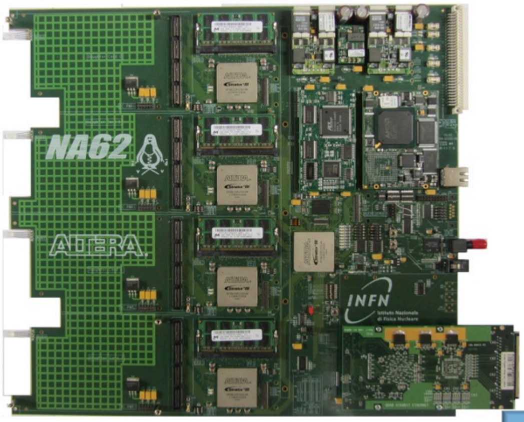
- We already built at LNF 9 out of the 12 LAV stations
- 8 them are already been installed inside the cavern and the vacuum tank
- The decay region has been already evacuated to the pressure of ~10^{-5} mbar
- 3 LAV are currently in use the technical run fully equipped with readout

NA62 LAV readout chain

LAV station

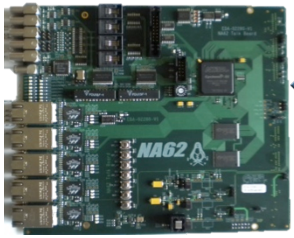
FE board

Readout TEL62



PC Farm

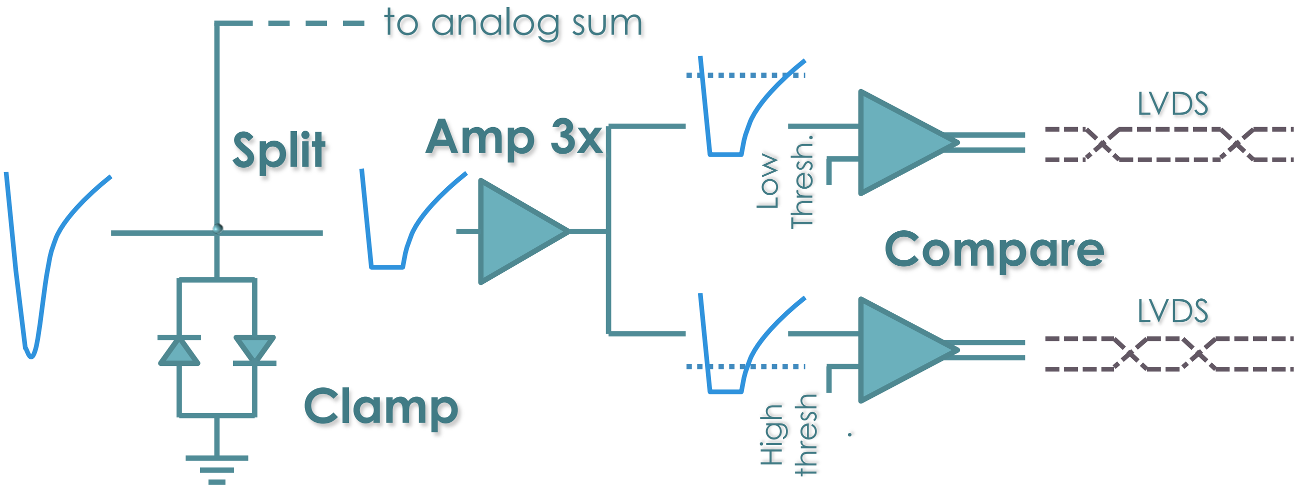
L0TP

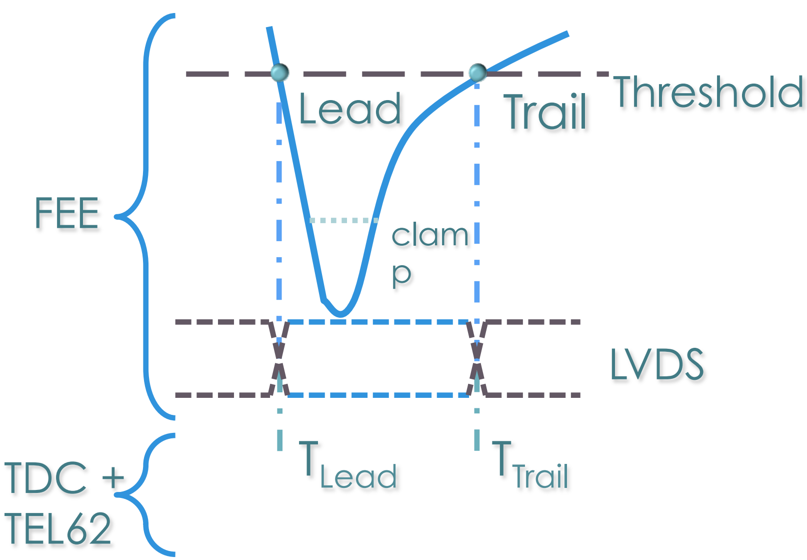


The LAV readout in numbers

- 2496 analog channels in 12 stations
- 4992 digital output to TEL62
- 100 FEE boards + 12 TEL62 boards
- ~ 100 KHz max rate per channel
- Requirements
  - ✓ Time resolution <1 ns,
  - ✓ energy resolution <10% at 1 GeV (using Time over Thr ToT)

LAV front end working principle

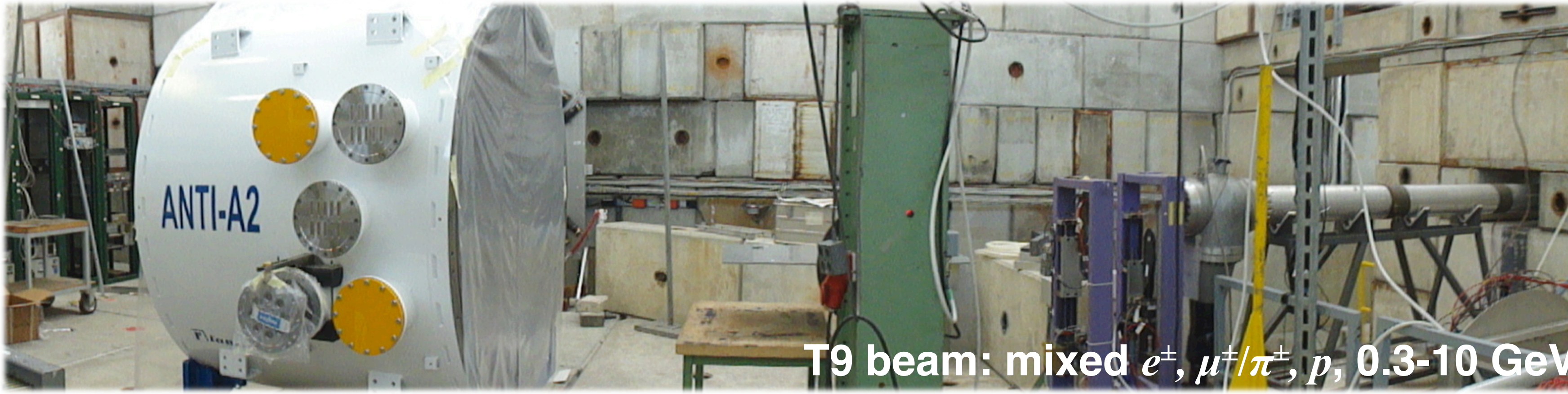


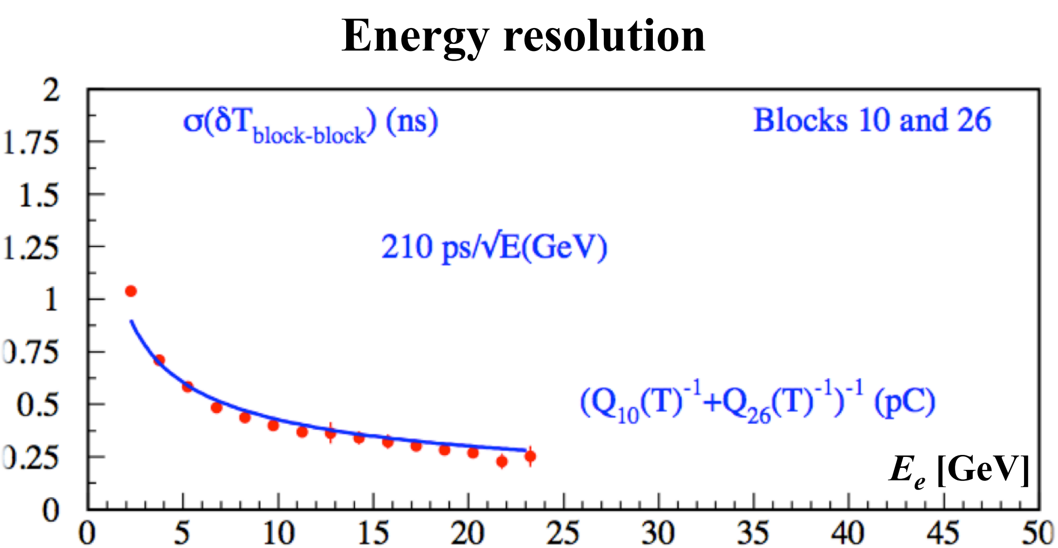


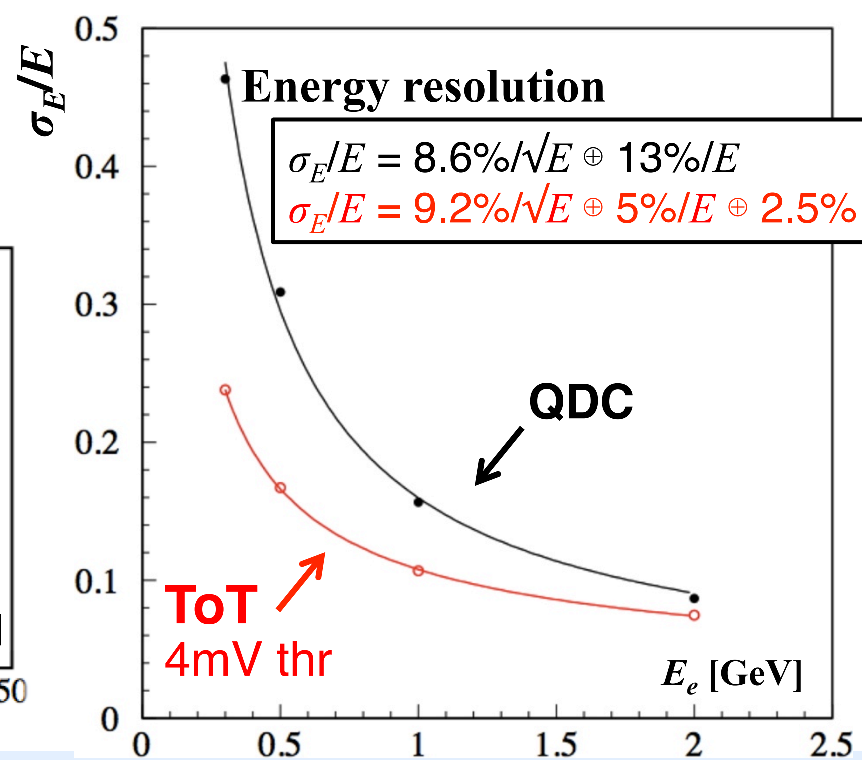
ToT$=T_{Trail}-T_{Lead}$

- Split the input signal in two:
  1 copy to comparator + 1 to analog sums;
- Clamp the signal preserving its width;
- Amplify the signal x3 to restore the overdrive;
- Compare signal with 2 independent thresholds
- Produce an LVDS signal and send the signal to the digital read out board TEL62;
- Measure the leading and trailing times of the signal and compute the ToT=Trail-Lead;
- Use a parameterization to compute Q(ToT)

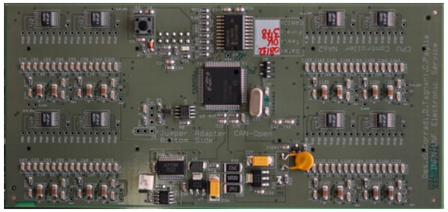
A2 test beam CERN-PS, Aug/Sep 2010





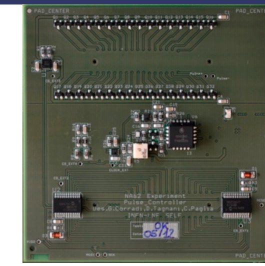


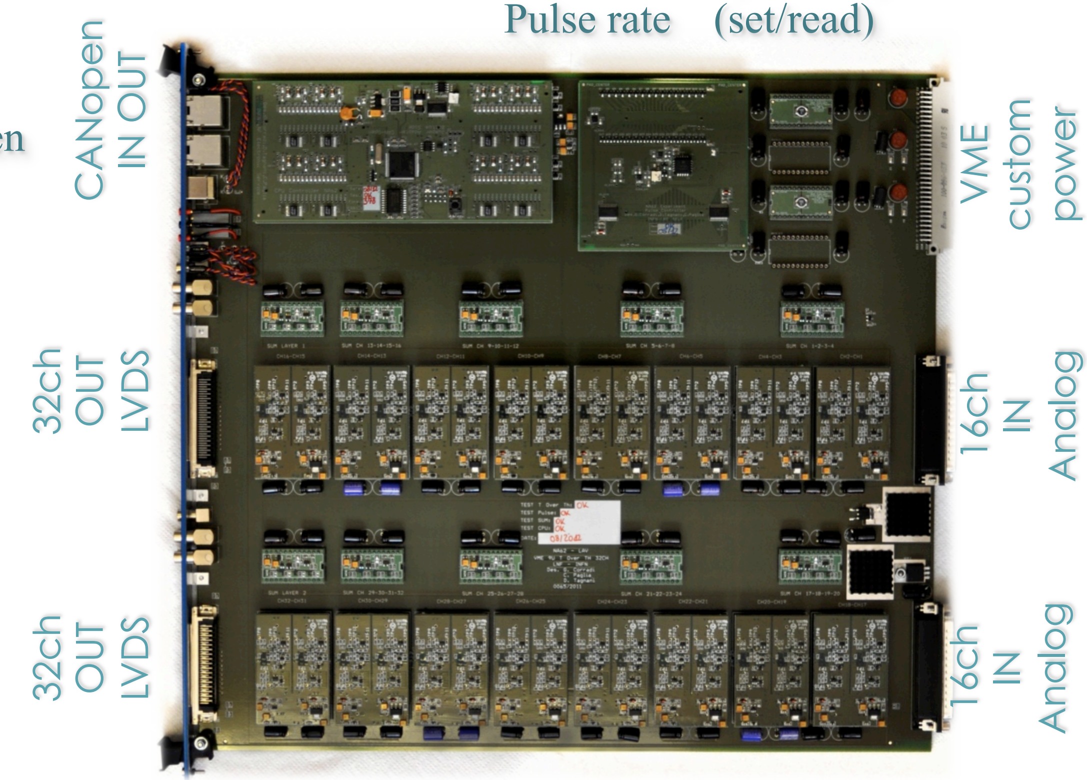
The LAV Front End Board (LNF)

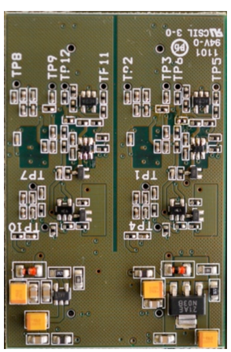


Board controller (1x)
Communicate using CAN-Open
Allows setting and reading:
Thresholds (set/read)
Power connection (read)

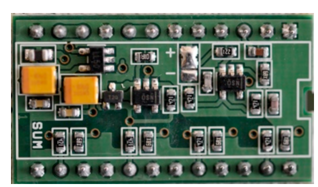
Test pulse controller (1 x)
Pulse height (set/read)
Pulse width (set/read)
Pulse rate (set/read)







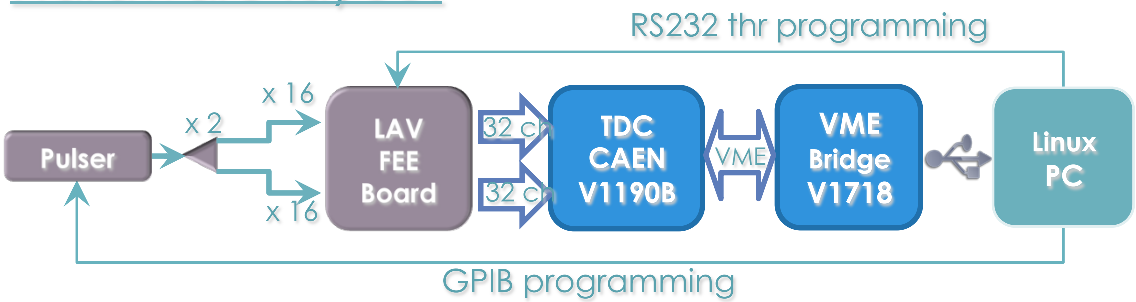
ToT mezzanine card (16 x)
2 channels and 2 threshold per board.
Threshold range 5-250 mV
Includes the circuits for: Clamp, Amplifier, Comparator & LVDS driver.



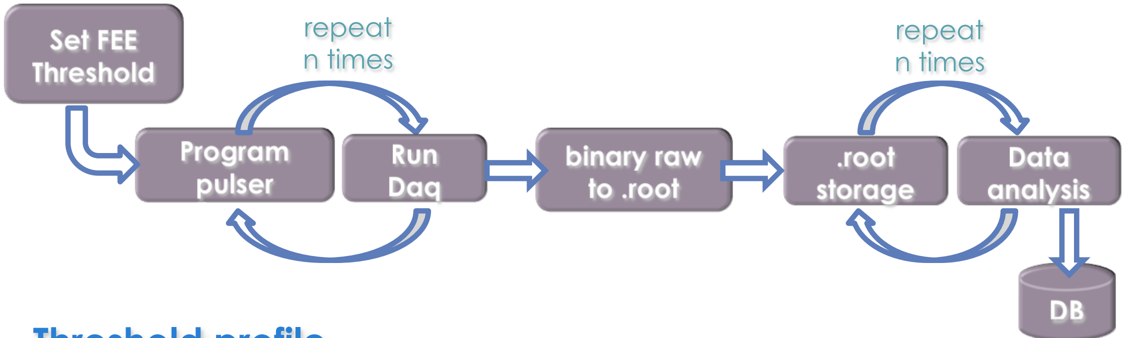
Sum mezzanine card (10 x)
Sum 4 analog channels (8 x)
Sum 16 analog channels (2 x)
Connected to a 50W LEMO out

LAV Front end automatic test stand (LNF)

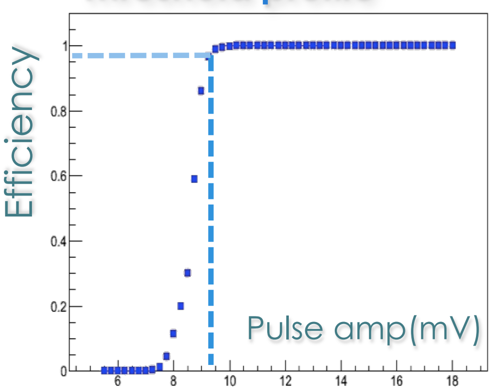
Hardware layout



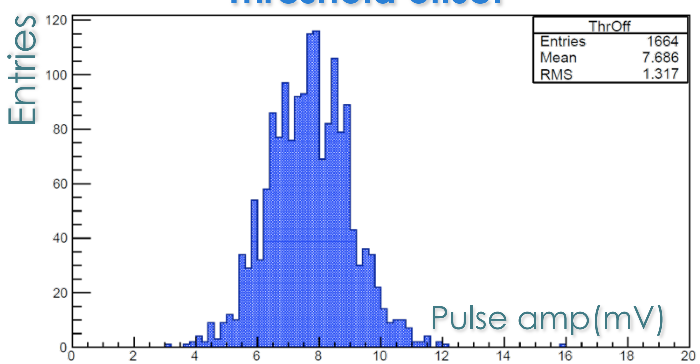
Software flow chart



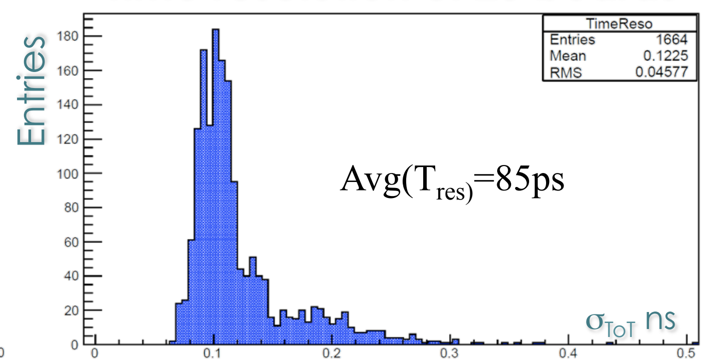
Threshold profile



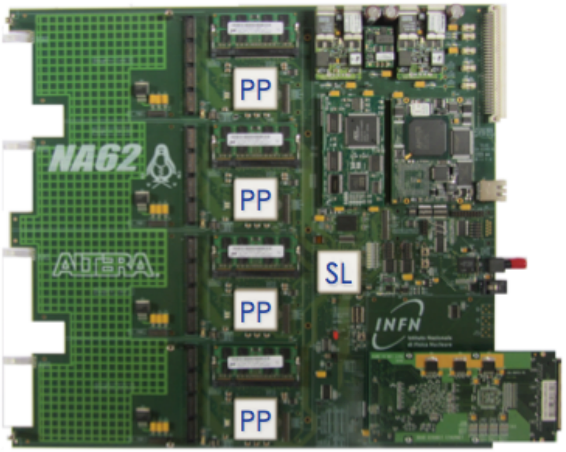
Threshold offset



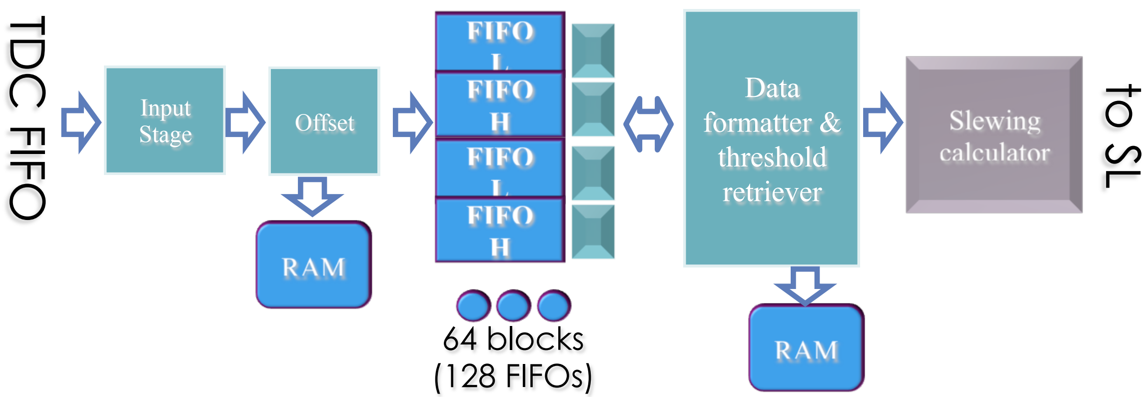
Time resolution of 26 boards



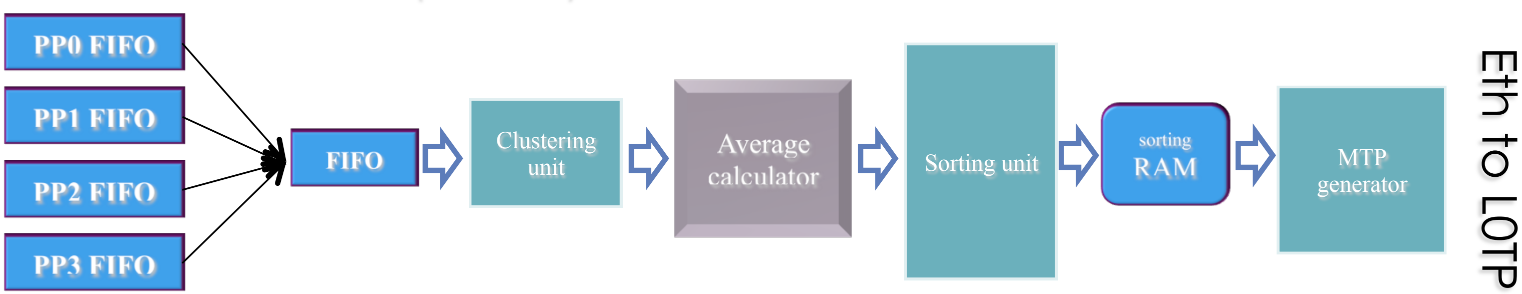
The LAV trigger primitive generator



- Corrects single hits for time slewing and detector offset
- Collect hits pertaining to the same particle
- Produce average hits time and compute event time
- Sort event times and send the list to L0TP



$$T_0 = T_L - L_{THR} \cdot \frac{T_H - T_L}{H_{THR} - L_{THR}}$$



2012 technical run achievements (so far…)

- Integration of 3 LAV station into the NA62:
  - Cabling of the detector completed
  - Detector Control System remote control
  - Full test of readout chain
- Development of analysis tool
  - Standalone monitoring and analysis programs
  - Integration with official data reconstruction
  - Online monitor
- Analysis of first data from detectors
  - Noise levels under control in all stations
  - Time alignment with detector clocks OK
  - Physics run with "$\pi^+\pi^0$" trigger done during Sunday night (some 10^6 events on disks)

CERN Bulletin

Nos 45-46 | 5 & 12 November 2012
More articles available at: http://bulletin.cern.ch

All new for NA62

A Large Angle Veto detector in place in the NA62 decay volume.

This week sees the start of the first run of the new NA62 experiment. This will be a unique opportunity for the collaboration to test its new beam, new detectors and new data acquisition system before the physics run in 2014. Speaking to the Bulletin, the NA62 technical coordinator Ferdinand Hahn shares the many challenges that the various teams faced to be on time for beam. Ready, steady, start!

With components from almost all the detectors in place downstream of the decay point of the mother particles – the kaons – and of the KTAG detector that tags the kaons before they decay, NA62 is ready for its first technical run. This unique run will test all the equipment as well as the trigger and the data acquisition systems. "This year, we will have about five weeks of beam from the SPS before the long shutdown of all the CERN machines," says Ferdinand Hahn, NA62 Technical Co-ordinator. "During that long shutdown, and before the restart of the injector chain, we plan to complete the installation of all the remaining detectors."

Once completed, the NA62 experiment will be CERN's flagship for the study of rare kaon decays, in particular that where the mother particle decays into a pion and two neutrinos. "Studying rare processes like those involving kaons allows us to make precise tests of the Standard Model as their theoretical predictions are very good," says Augusto Ceccucci, NA62 Spokesperson. "By measuring the rate of some of these decays, we will be able to determine a combination of Cabibbo-Kobayashi-Maskawa matrix elements independently. Discrepancies compared to expectations might be a signature of new physics."

A word from the DG

From the Jura to Japan…

Fifty years ago, a week-long school for physicists took place in Saint Cergue, in the Jura mountains not far from CERN. Its focus was on using emulsion techniques, but its legacy was much more far reaching. Last week I was in Fukuoka, Japan, on the last day of a direct descendent – the first Asia–Europe–Pacific School of High-Energy Physics (AEPSHEP).

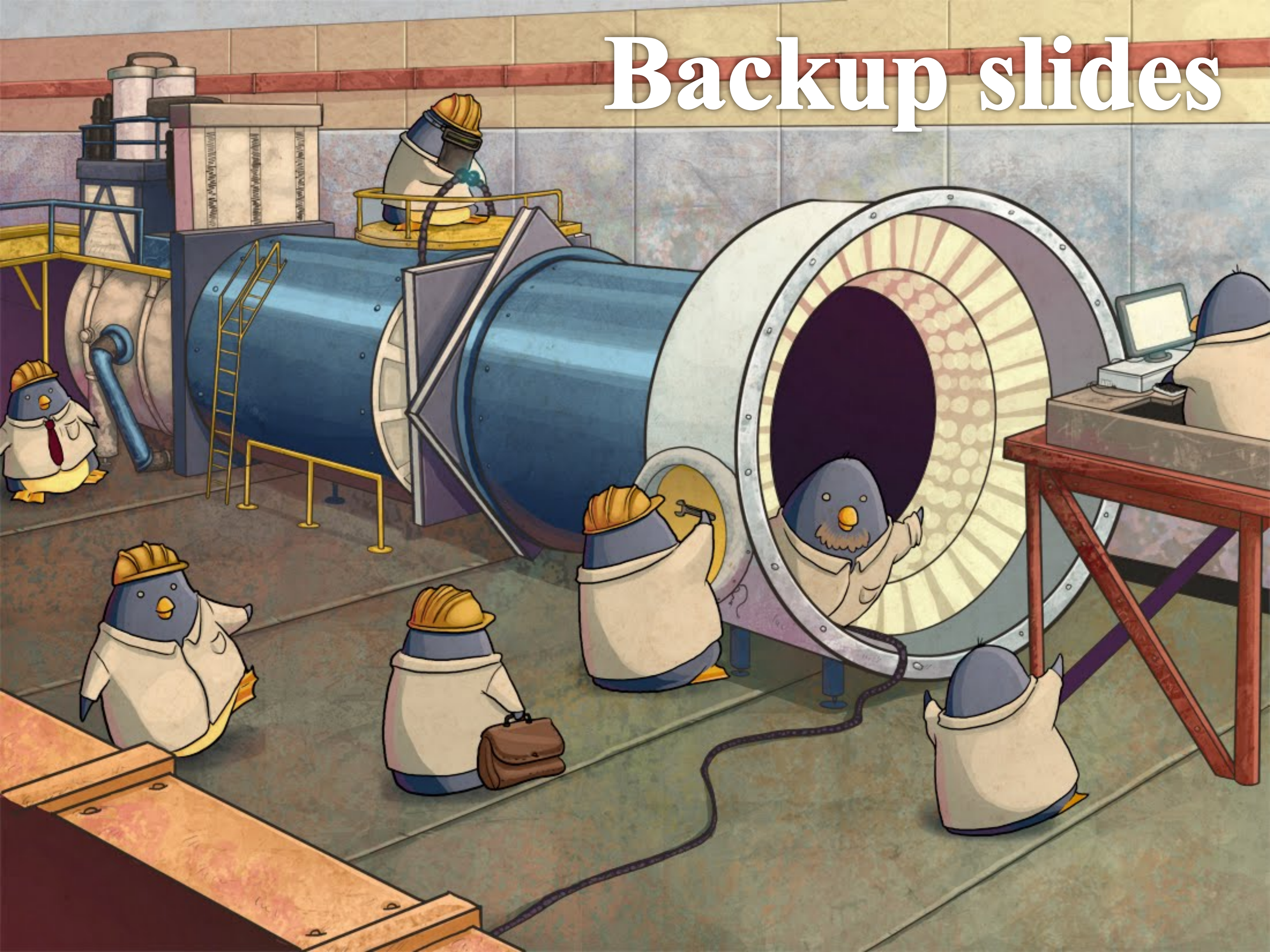
(Continued on page 3)

In this Issue

Conclusions

- The LNF group has played a leading role in all aspects of the construction and installation of the LAV of the NA62 experiment:
  - Detector design, testing, assembly and installation
  - Electronic design, production and testing
  - Leading role in the software development
- Our group now heavily involved in the present technical run.
- We would like to thank:
  - LNF SPAS: C. Capoccia, A. Cecchetti, E. Capitolo
  - Group technicians: R. Lenci, V. Russo, M. Santoni, S. Valeri, T. Vassilieva
  - LNF SELF: G. Corradi, C. Paglia, D. Tagnani
  - LNF vacuum service: P. Chimenti, V. Lollo
  - LNF mechanics workshop: G. Bisogni

Backup slides



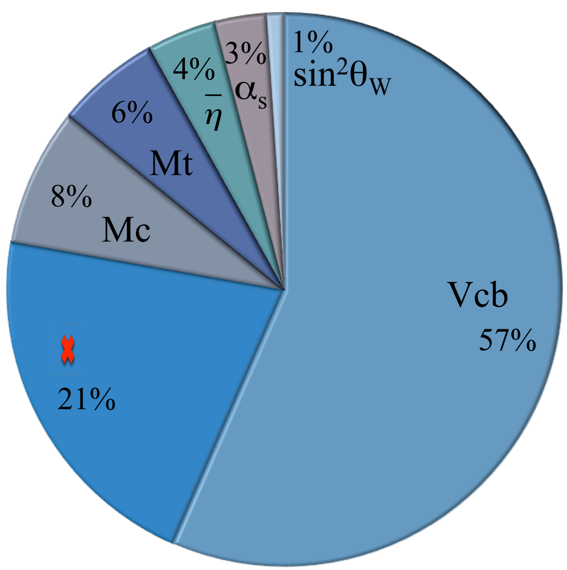
Theoretical expectation for BR

J. Brod, M. Gorbahn, and E. Stamou Phys. Rev. D 83, 034030 (2011)
full two-loop electroweak corrections to the top-quark contribution X_t

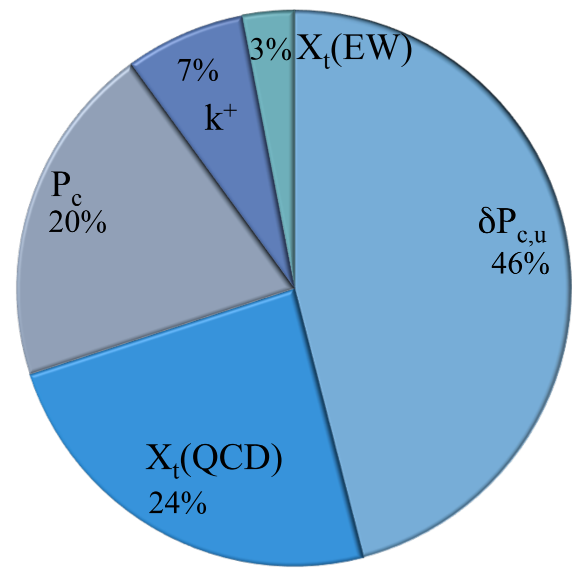
$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (7.81^{+0.80}_{-0.71} \pm 0.29_{theo}) \cdot 10^{-11}$$

10% 3.7%

Parametric error dominated by CKM



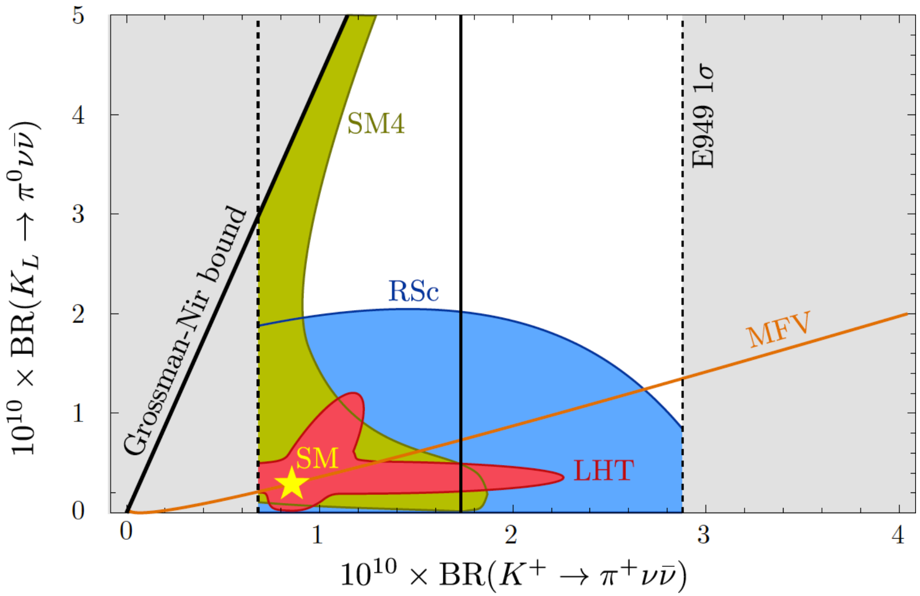
Theory dominated by charm



The combination of tiny BR and high precision theoretical prediction allows to spot even for small deviations from SM induced by new physics degrees of freedom

What we can learn from K→πνν

New physics models



SM4: SM with 4th generation (Buras et al. '10)

RSc: Custodial Randall-Sundrup (Blanke '09)

LHT: Littlest Higgs with T parity (Blanke '10)

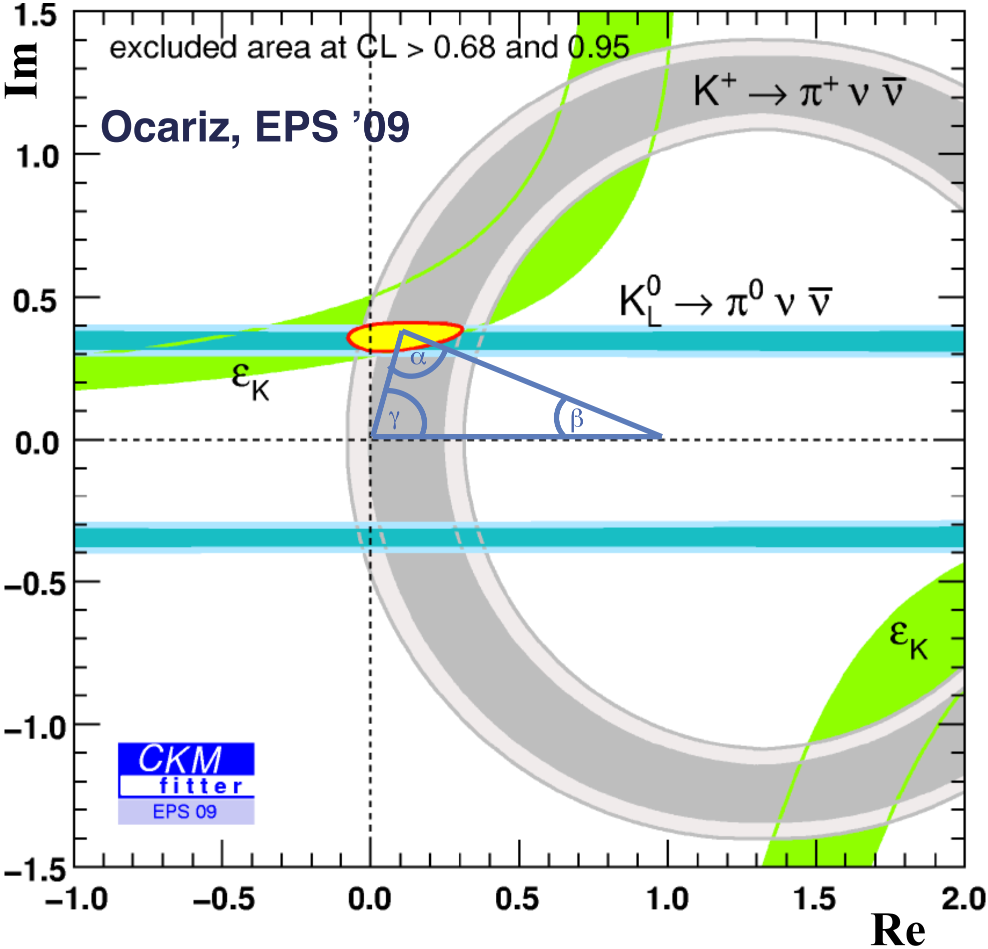
MFV: Minimal flavor violation (Hurth et al. '09)

CKM constraints from:

$BR(K^+ \to \pi^+ \nu\nu)$ to ±10%

$BR(K_L \to \pi^0 \nu\nu)$ to ±15%

ε_K to resolve ambiguities



What's next: $K_L \to \pi^0 \nu\nu$

- **Potential for future running with K_L beam?**
- $K_L \to \pi^0 \ell^+ \ell^-$ BRs could potentially be measured without significant upgrades
  - FCNC decays with CP-violating components
  - Useful in constraining the unitarity triangle
- $K_L \to \pi^0 \nu\nu$ need important intervention on photon vetos
  - We are starting investigation on possible LAV upgrades

Sensitivity to LFV modes in NA62

Mode	Acceptance, A	$\mathrm{UL}(90\%\mathrm{CL}) = 2.44/\Phi_K/A$
$K^+ \to \pi^+\mu^+e^-$	$7.8\%(6.7\%)$	$2.6(3.1) \times 10^{-12}$
$K^+ \to \pi^+\mu^-e^+$	$7.9\%(6.5\%)$	$2.6(3.2) \times 10^{-12}$
$K^+ \to \pi^-\mu^+e^+$	$8.1\%(6.6\%)$	$2.6(3.1) \times 10^{-12}$
$K^+ \to \pi^-e^+e^+$	$5.0\%(3.6\%)$	$4.1(5.8) \times 10^{-12}$
$K^+ \to \pi^-\mu^+\mu^+$	12.5%	1.7×10^{-12}
$K^+ \to \mu^-\nu e^+e^+$	$2.9\%(1.6\%)$	$7.2(12.8) \times 10^{-12}$
$K^+ \to e^-\nu\mu^+\mu^+$	$5.5\%(4.5\%)$	$3.7(4.6) \times 10^{-12}$
$\pi^0 \to \mu^+e^-$	$2.4\%(1.3\%)$	$4.1(7.6) \times 10^{-11}$
$\pi^0 \to \mu^-e^+$	$4.2\%(2.2\%)$	$2.4(4.5) \times 10^{-11}$

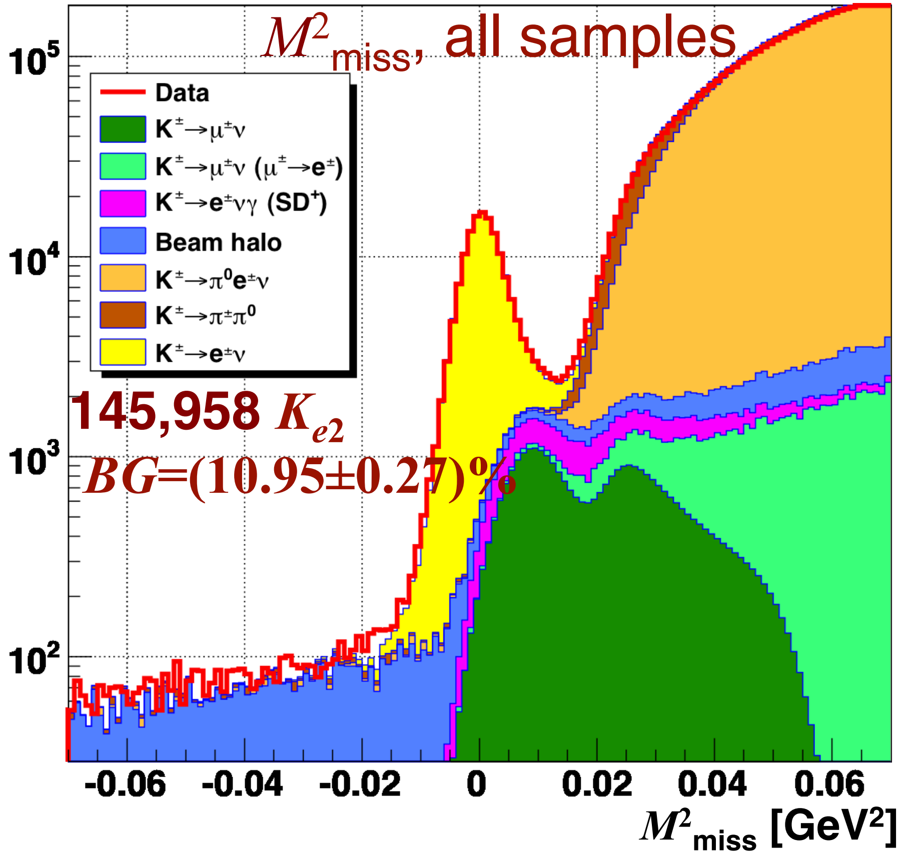
* Lower acceptances for electrons include effect of trigger energy threshold

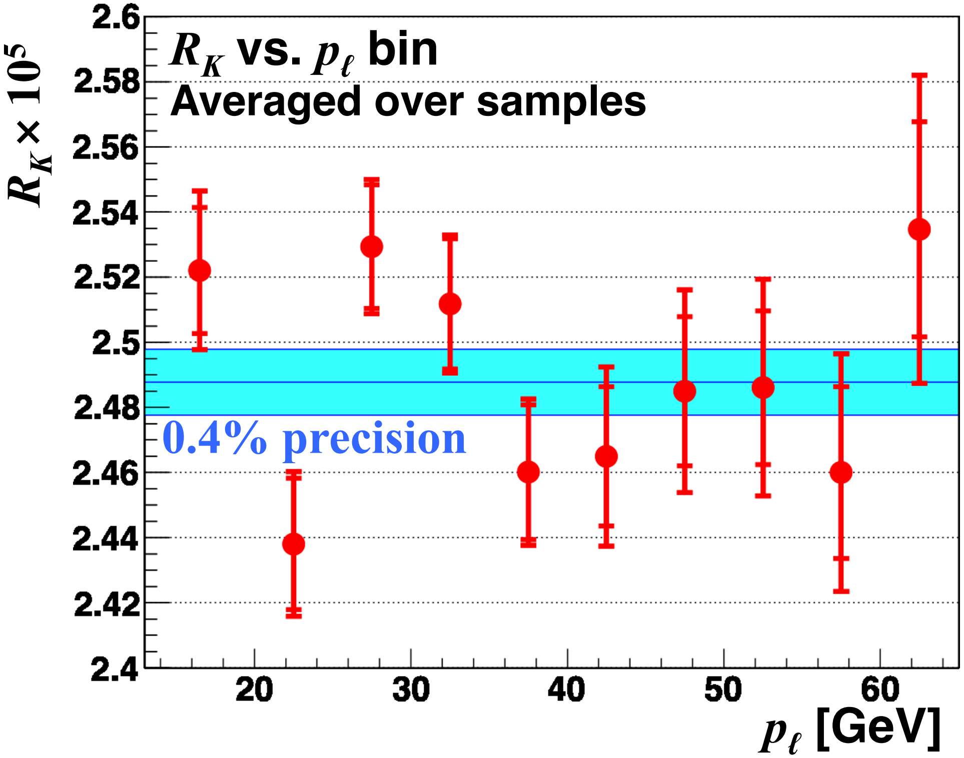
Only geometrical/trigger efficiency, various assumptions & simplifications:

- Nominal kaon flux: $\Phi_K = 5.9 \times 10^{12}$/yr for 105 m < z < 180 m
- Flat phase space distributions
- 2 years of data taking
- No backgrounds

Trigger rates compatible with main physics program

NA62 R_K



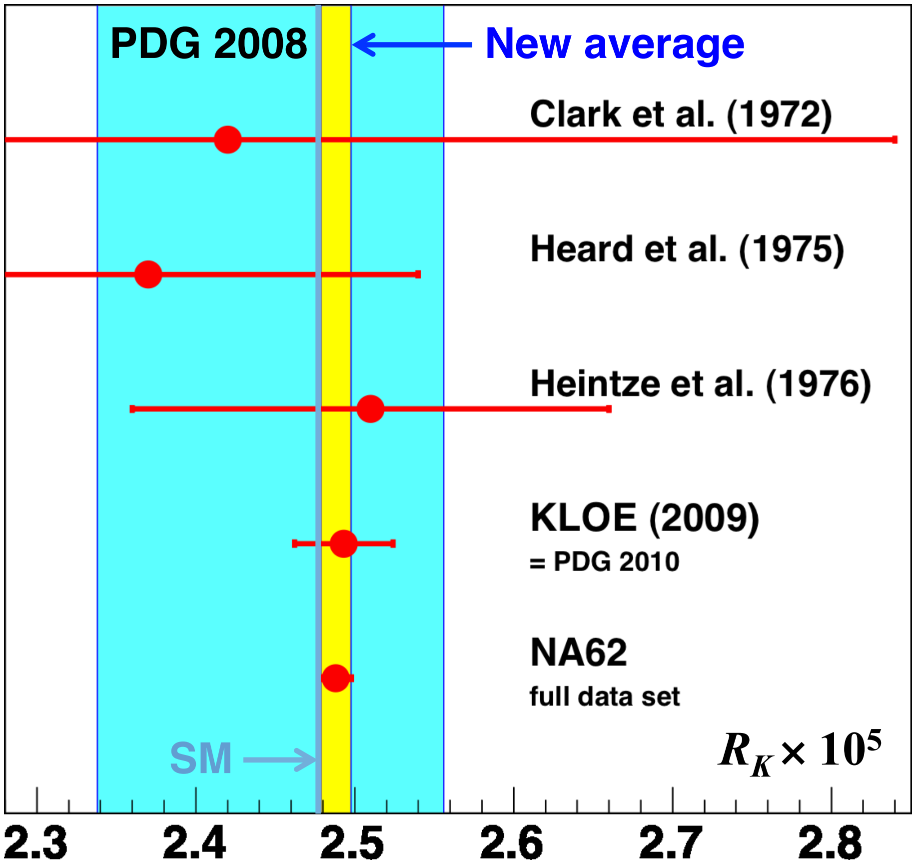


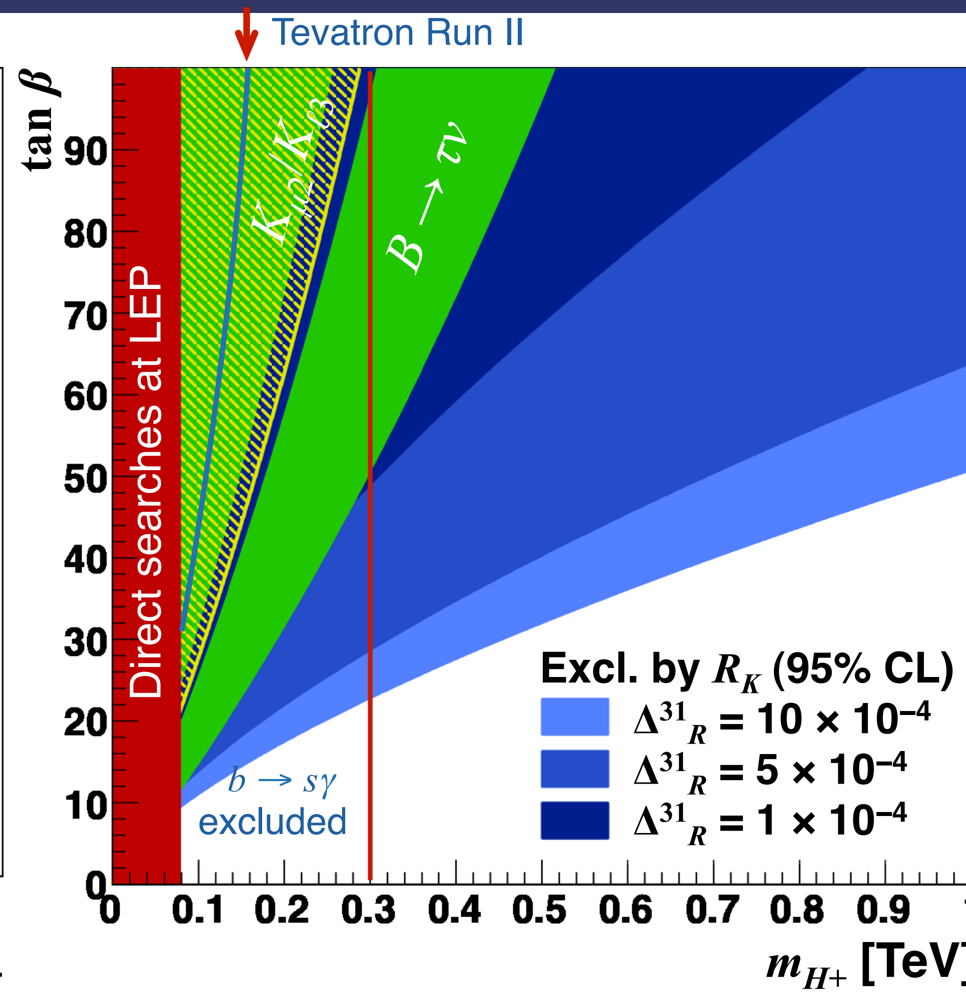
$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst})\times10^{-5} = (2.488 \pm 0.010)\times10^{-5}$$

Updates previous NA62 result (40% data set)

$R_K = (2.487 \pm 0.013) \times 10^{-5}$ PLB698 (2011) 105

R_K world average





Average	$R_K \times 10^5$	$\delta R_K/R_K$
PDG 2008	2.447±0.109	4.5%
Current	**2.488±0.009**	**0.4%**

MSSM with *R* parity

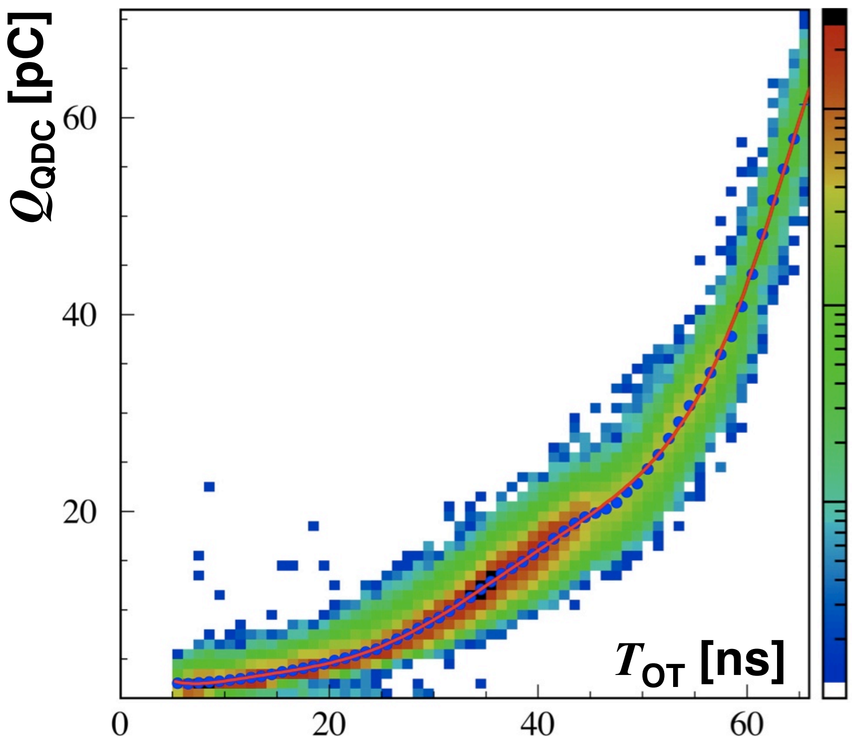
$$R_K^{\mathrm{LFV}} \approx R_K^{\mathrm{SM}} \left[1 + \frac{m_K^4}{m_H^4} \frac{m_\tau^2}{m_e^2} |\Delta_R^{31}|^2 \tan^6 \beta \right]$$

Cost review

Core funding assigned by INFN to the NA62 experiment

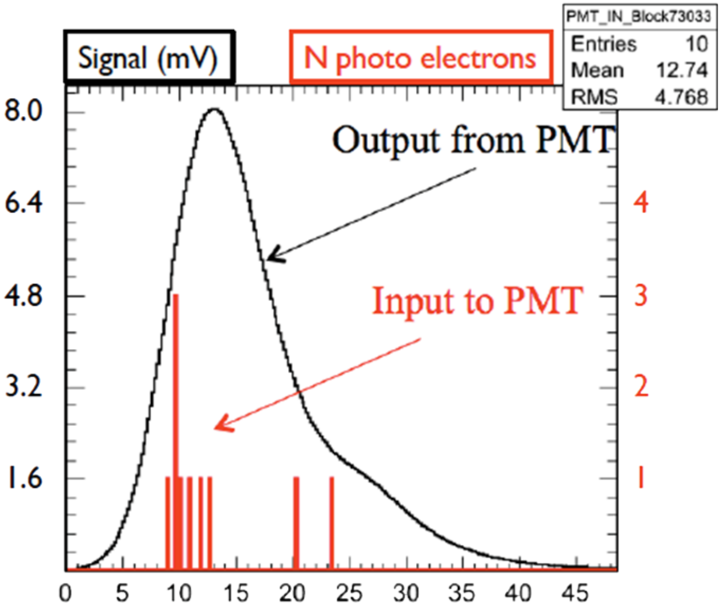
k€/year	*2009*	*2010*	*2011*	*2012*	*2013*	*Total/item*
GT	*320*	*300*	*130*	*0*	*0*	*750*
LAV	*430*	*600*	*570*	*200*	*0*	*1800*
RICH	*590*	*220*	*140*	*50*	*0*	*1000*
TDAQ	*60*	*80*	*260*	*450*	*100*	*950*
GRID+computers	*0*	*0*	*50*	*100*	*100*	*250*
Total/year	*1400*	*1200*	*1150*	*800*	*200*	*4750*

Charge reconstruction in LAV



- Measure ToT vs. charge using QDC and TDC only during calibration not during experiment
- Fit the function Q(ToT) (i.e. polynomial function)
- During data taking, measure the time using a TDC only

Simulations



Digitization simulation

PMT simulation correctly treats:

- Path fluctuations for optical photons
- PMT photocathode QE()
- Dynode by dynode gain fluctuations

Front end electronic simulation includes

- Cable length simulation
- Threshold simulation
- Hysteresis simulation

INPUT to simulation from GEANT4

- Number of photons in the event
- Arrival time of each photon
- Photon wavelength